

Solar Radiation, Temperature and Humidity Measurements in Sohar-Oman

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Abstract— This paper presents real measurements of Direct Solar Radiation (DSR), Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI), Temperature and Humidity in Sohar-Oman (21° N, 57° E) throughout the year, with the existing meteorological conditions encountered. Real-time, high resolution solar radiation and other meteorological data were collected and processed. Monthly and daily statistics of DSR were calculated from the one-minute average recorded by the weather station. The highest one-minute average daily DSR was recorded as 937 W/m². The highest monthly and daily mean DSR values were recorded as 730 and 493.5 W/m², respectively. In addition to DSR, surface temperature variations, the daily average clearness indexes, and relative humidity variations are discussed. When possible, DSR and some meteorological data are compared with corresponding data of the 22-year average of NASA's surface meteorology model, Department of Meteorology-Oman (1987-1992) and author measurements. The measured data (DSR and meteorological) are in close agreement with the NASA SSE model and Department of Meteorology-Oman (1987-1992) with some discrepancy.

Index Terms—Solar energy, direct beam radiation, temperature, humidity, meteorological information

I. INTRODUCTION

THE continuous increase in global energy demand, depletion of fossil fuel, and fluctuation of oil prices, global warming and many other problems the human kind needed to renewable and sustainable energy source RSES became crucial. Renewable energy sources are many and their potential is different from region to another. Solar energy could be the most important one, where it is free, clean and renewable. In general, there is potential of solar energy in the Gulf Cooperation Council (GCC).

Procuring data on the availability of RER in specific localities is a crucial task. The focus of this study is to knowledge solar radiation data in Oman, which is important for the design and development of solar energy-based projects.

The efficiency of PV cells is influenced by high air temperature, humidity, wind speed, and dust contamination (a potentially major issue in the Arabian Peninsula). The environmental conditions in Oman are expected to reduce the efficiency of PV cells compared to standard conditions, and

obtaining good estimates of this effect is important for assessing the feasibility of a solar-driven project.

The area of Oman, which is located in the Middle East, is 212,460 km², with 2092 km² coastline. The longitude and latitude is (57° 00'E, 21° 00'N). Oman has very hot weather condition, where the temperature approaching 48 °C in summer between May and September. Dry with little rain season is the condition in most of Oman regions with humid weather near the coastal regions [1]-[4].

In 2007, the electrical demand in Oman reached to 2,773 MW in comparison to 5,691 MW, in 2014 [1]. The peak demand expected to increase with the growth in industry and population, where the annual growth rate is 9%. The local consumption of natural gas is around 19% of the production, where 92% of this consumption is used as fuel in electrical power plants [3]. Variety in fuel resources is important for Oman, specially the use of renewable energy due to suitable.

Solar radiations have been measured globally in various parts in the Gulf region [4]-[22], and still direct beam solar radiation data are incomplete. Investigations and studies based on different models have been performed to estimate solar energy. Abdalla and Baghdady have measured global and solar radiation in Doha [4]. Some methods of predicting global solar radiation have been examined. The diffuse component of solar radiation was predicted by two methods. Comparisons of diffuse solar radiation in Dhahran with the two methods results have been done.

Ultraviolet solar radiation at Dhahran has been measured by Elhadidy et al. [5] for one complete year. Al Mahdi et al. [6] have performed a statistical assessment of the accuracy of 12 solar radiation models for five meteorological stations in the Gulf Arabian states. Hamdan [7] have measured solar radiation data for a complete year in Amman. He found that the annual average daily diffuse radiation was 4.5 MJ/m² and total solar radiation was 20.4 MJ/m². Al-Hinani and Al-Alawi [8], investigated monthly average daily global solar radiation in Oman. Six stations have been used in this investigation over a period of six years. The measurements lead to estimate the clearness index for a typical day for each location. Kazem et al. [9] have measured horizontal solar irradiance and sunshine duration for three months period from March 2010 to the end of May 2010 in Sohar-Oman. It is found that the average sunshine hours is 10.23, the average solar radiation is 5.92 kWh/m²/day and average solar radiation is found to be 248 (W/m²). Islam et al. [10], measured direct solar radiation in Abu Dhabi over a period of one complete year. It is found that

the highest mean daily solar radiation is 730 W/m². However, the measured monthly mean solar radiation is 493.5 W/m². In this study the measurements was compared with the “22-year average data from the NASA Surface Meteorology” [23] and “Department of Meteorology-Oman (1987-1992)” [24].

II. SOLAR ENERGY CALCULATION

Solar radiation is consist of or categorized into two essential portions, extraterrestrial radiation (G_{extra}) and global irradiation (G_T) [13, 15] as shown in Fig. 1. G_{extra} , is represented in equation 1

$$G_{extra} = I_o \left[1 + 0.034 \cos \left(\frac{2\pi N}{365} \right) \right] \quad (1)$$

In this formula

I_o is a constant value named as solar constant, it equals to 1,367 W/m²,

N is the day number (first of January is the day number one $N=1$).

Where

(α) is the altitude angel. It is the angle stuck between the dropped beam and the plane.

(ϵ) is the incidence angle. It is the incidence from the zenith line.

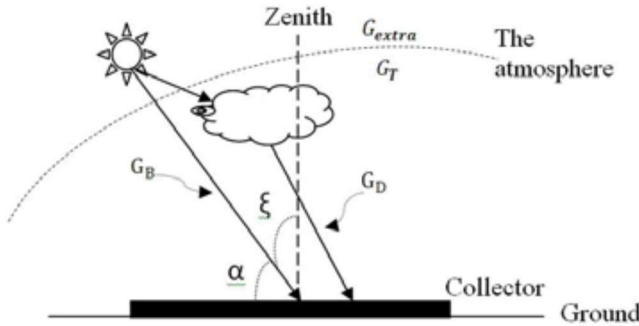


Fig. 1. The mechanisms of solar irradiation on a plane surface [15].

In horizontal surface, both incidence and zenith angles (θ) are equaled. This is the reason behind not mention it in the figure.

(ϵ) can be found from the next equations

$$\alpha - \epsilon = 90 \text{ (AM)} \quad (2)$$

$$\alpha + \epsilon = 90 \text{ (PM)} \quad (3)$$

in which the altitude angel (α) is given by,

$$\sin \alpha = \sin L \sin \delta + \cos L \cos \delta \cos H_s \quad (4)$$

Where H_s is the hour angle.

Hour angle also called as the angular displacement of the sun from the local location, it comes with a negative value during Post Meridiem (PM) and a positive value at during Ante Meridiem (AM). It can be found from the next equations.

$$H_s = 15(t_s - 12 \text{ hour}) \quad (5)$$

Variable t_s represent solar time. It measures the time duration based on sun position from the earth which is varied according to the orbit and ellipse of the earth. t_s can be calculate from the next equations.

$$t_s = LMT + EOT \pm 4^\circ (L_{zt} - LOD) \quad (6)$$

Here, the variable of

LMT Represents the instant time during calculation.

EOT Represents the equation of time.

L_{zt} Represents the local standard meridian.

EOT is the variance of the two time's parameters, (apparent solar) and (mean solar), with the same physical longitude, at the same real instant of time. Both parameters are taken at a given location or at another location. EOT can be found from the next equations

$$EOT = 9.87 \sin(2B) - 7.53 \cos(B) - 1.5 \quad (7)$$

Where B can be calculated by using,

$$B = \frac{360}{365} (DN - 81) \quad (8)$$

The local standard meridian (L_{zt}) is given as,

$$L_{zt} = \text{time zone in GMT} \times 15 \quad (9)$$

To measure the global solar irradiation which represented by (GHI) for tilted surface, three portions must be considered, DHI , DNI and RHI . GHI can be calculated by using,

$$GHI = DHI + DNI + RHI \quad (10)$$

Where

DHI is diffused solar radiation. It is the scattered radiation in the sky by clouds and other particles effects.

DNI is beam (direct) solar radiation. It is the beam which drops directly coming from the sun

RHI is reflected solar radiation. It is the reflected radiation that generated from the reflection of other radiation.

RHI is equivalent to zero when work was on a horizontal surface, in this case, GHI can be found from the next equations

$$GHI = DHI + DNI \quad (11)$$

It important to consider the variable (I_{extra}) hence, to have a good image about the solar radiation (I_{extra}) indicates the whole solar energy before the atmosphere field. On other hand (GHI) indicates the solar energy after the atmosphere field. However, (I_{extra}) can be calculated using the next formula.

$$I_{extra} = G_{extra} S_o \quad (12)$$

$$GHI = G_T S_o \quad (13)$$

$$DNI = G_B S_o \quad (14)$$

$$DHI = G_D S_o \quad (15)$$

The value for (I_{extra}) is given by.

$$I_{extra} = \left\{ I_o \left[1 + 0.034 \cos \left(\frac{2\pi N}{365} \right) \right] \right\} \times S_o \quad (16)$$

Where S_o is the length of day, which can be calculated by

$$S_o = \frac{2}{15} \cos^{-1}(-\tan L \cdot \tan \delta) \quad (17)$$

L Represents latitude while δ represents angle of declination, which can be calculated by

$$\delta = 2.345 \sin \left[\frac{360(284 + N)}{365} \right] \quad (18)$$

The global (GHI) can be calculated using (I_{extra}) as below, where K_T is the clearness index

$$\frac{GHI}{I_{extra}} = K_T \quad (19)$$

III. EXPERIMENTAL SETUP AND PROCEDURE

A measuring station was located at the Sohar city-Oman (24 20 N, 56 40 E). This study was carried out in 2015 for complete year period. The measuring instruments were set 12 meters from the ground level. For this purpose, the WE300 - Rugged solar radiation transmitter detector (4-20 ma), Range: 0 to 1500 W/m²; spectral response: 400 to 1100 nm; 22.5 m cable, was used to measure the solar radiation intensity. A WE710 PV Panel backside surface temperature sensor type: 100 Ohm, platinum class a RTD, Output: 4-20 ma, (-50°C to +85°C) was used to measure the panels temperatures. This device has an accuracy of $\pm 0.25^\circ\text{C}$; and wires length were 22.5 m cable. A WE700 + WE770 air temperature sensor with solar shield temperature sensor type: precision RTD, has an output: 4-20 ma, range: -50°C to +50°C, 22.5 m cable, was used to measure the ambient temperature. A REAM-Data Acquisition System of 16 Analogue Channels (4-20mA, 0-5V, 0-10V and 0-24V) NISE 104-Computer Dual Core Atom D2550 1.86GHz, 2GB RAM, 32GB SSD, 17" IP65 1024 x 768 Touch Screen with Software: DART (Data Acquisition Real Time) was used to measured and record variables on the renewable energy lab computer for 24 hours a day and 365 days.

IV. RESULTS AND DISCUSSION

The solar radiation measured for complete year is shown in Fig. 2. It is clear that the solar radiation is more than 600 W/m² throughout the year, which suggest that solar photovoltaic systems could be effective in this area. However, the lowest and highest daily solar radiation recorded was in March and July, respectively, as shown in Fig. 3. Direct Normal Irradiance (*DNI*), Diffuse Horizontal Irradiance (*DHI*) and Global Horizontal Irradiance (*GHI*) are shown in Fig. 3.

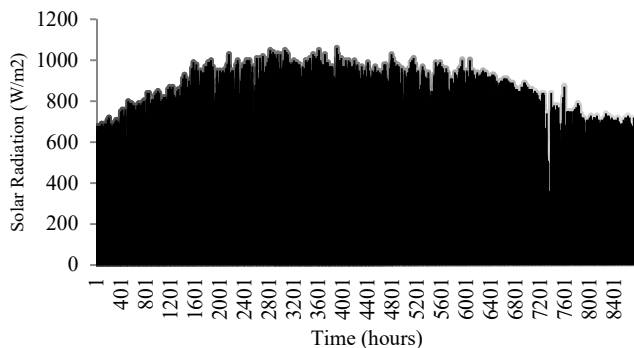


Fig. 2. Solar radiations for Sohar, mean hourly data

DNI represents the maximum possible beam radiation that is measurable. *DHI* is defined as the radiation scattered by aerosols, dusts and particles. *GHI* it is the total amount of the direct and diffuse solar radiation as calculated using the following formula: $GHI = DNI \cdot \cos(\theta) + DHI$, where θ is the Zenith Angle.

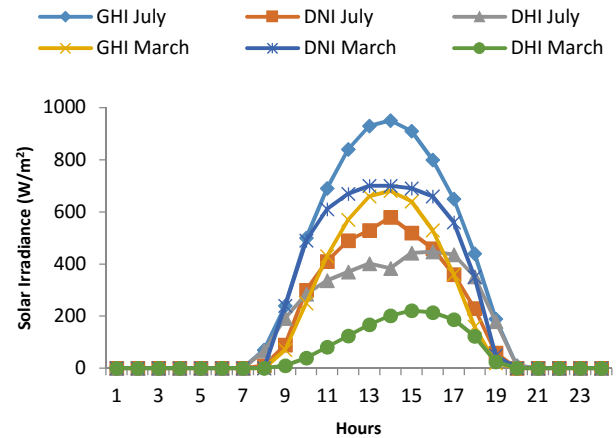


Fig. 3. Daily solar radiations for Sohar, mean hourly data for July and March 2015.

TABLE I
MONTHLY MEAN DAILY VALUES OF DIRECT BEAM SOLAR RADIATION FOR SOHAR

Months	Direct radiation, (kWh/m ² /day)				Clearness
	NASA SSE model (22-year average)	Department of Meteorology-Oman (1987-1992)	Renewable Energy Lab, Sohar University 2015	Average	
Jan	4.45	4.14	4.32	4.30	0.607
Feb	5.15	4.69	5.02	4.95	0.592
Mar	5.77	5.39	5.65	5.60	0.580
Apr	6.63	6.04	6.43	6.37	0.579
May	7.12	6.42	6.98	6.84	0.582
Jun	6.85	6.08	6.71	6.55	0.543
Jul	6.32	4.14	6.11	5.52	0.483
Aug	6.34	5.35	6.21	5.97	0.510
Sep	6.12	5.41	6.07	5.87	0.564
Oct	5.51	5.44	5.48	5.48	0.620
Nov	4.72	4.45	4.68	4.62	0.631
Dec	4.21	3.93	4.17	4.10	0.608
Ann	5.77	5.20	5.65	5.54	0.575

From Fig. 3, the maximum global solar radiation at the peak hour range between 950 and 680, in July and March, respectively. Table I illustrate the monthly mean daily values of direct beam solar radiation and clearness index for Sohar. Sohar solar radiation in kWh/m²/day measurement was compared with year average of NASA SSE Model [23],

Department of Meteorology-Oman (1987-1992) [24] and our measurements. Average of the three measurement has been taken. Also, the clearness index has been calculated. The first observation is that our measurements are in agree with that for NASA SSE and Department of Meteorology-Oman. From Table 1, the maximum and minimum solar radiations are 6.84 and 4.10 kWh/m²/day. The clearness index varies between 0.483 and 0.631 with average 0.575.

Figure 4 shows the daily temperature variation in Sohar for July and March 2015. The high temperature observed in summer was in July and it was range between 27.3-41.7 °C. On the other hand, the lowest temperature observed in March range between 12.9-28.9 °C. Sohar temperature measurement was compared with year average of NASA SSE Model, Department of Meteorology-Oman (1987-1992) and our measurements. Also, the monthly average of the three measured data has been calculated. It was found that the measurements are in close and almost agree, which mean that there are no significant variation in temperature. However, high temperature degrees in summer are promising to use concentrated solar power systems. Table II illustrate the monthly average measured temperature for Sohar. From Table 2 the highest average temperature found is 34.59 °C in June and the lowest found temperature is 20.51 °C in January.

Figure 5 shows the daily humidity for Sohar, mean hourly data for July and March 2015. It is clear that the humidity is high in the morning and lately evening. However, in summer (July) the humidity is high with respect to winter (March).

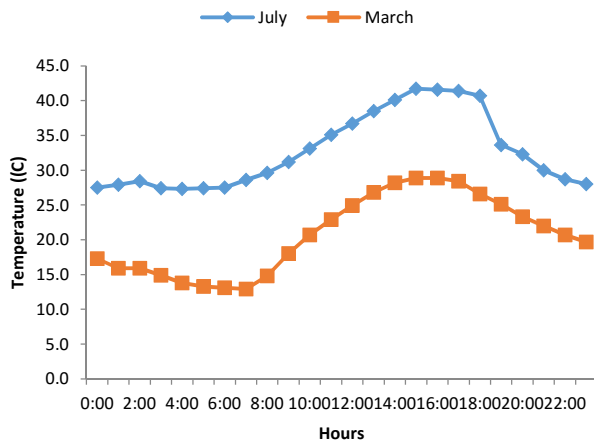


Fig. 4. Daily temperature for Sohar, mean hourly data for July and March 2015.

TABLE II
MONTHLY AVERAGE MEASURED TEMPERATURE OF SOHAR

Months	Temperature (°C)			
	NASA SSE model (22-year average)	Department of Meteorology-Oman (1987-1992)	Renewable Energy Lab, Sohar University 2015	Average
Jan	20.82	19.70	21.01	20.51
Feb	22.24	19.30	20.33	20.62
Mar	25.65	23.60	24.87	24.71
Apr	29.88	28.10	29.19	29.06
May	33.60	32.70	33.10	33.13
Jun	35.58	33.20	34.98	34.59
Jul	35.33	32.50	34.19	34.01
Aug	34.49	30.90	33.63	33.01
Sep	32.30	31.20	32.01	31.84
Oct	29.28	29.40	29.04	29.24
Nov	35.49	25.10	27.62	29.40
Dec	22.46	20.40	21.91	21.59
Ann	28.91	27.17	28.49	28.19

Table III illustrate the monthly average Relative humidity of Sohar. There is some differences between NASA SSE Model, Department of Meteorology-Oman (1987-1992) and our measurements. However, the average could give a useful compromise values. From Table III, it is found that the average highest humidity found in summer (August) is 60.39 and the lowest is 39.41, which is found in May.

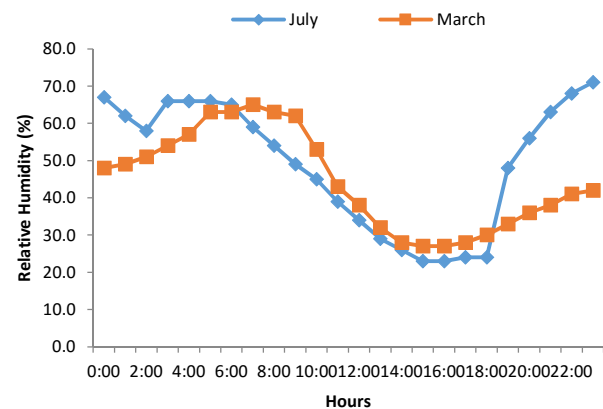


Fig. 5. Daily humidity for Sohar, mean hourly data for July and March 2015.

TABLE III
MONTHLY AVERAGE RELATIVE HUMIDITY OF SOHAR

Months	Relative humidity (%)			
	NASA SSE model (22-year average)	Department of Meteorology-Oman (1987-1992)	Renewable Energy Lab, Sohar University 2015	Average
Jan	45.32	63.00	58.00	55.44
Feb	43.47	60.00	59.00	54.16
Mar	38.66	60.00	56.00	51.55
Apr	31.68	54.00	47.00	44.23
May	27.23	49.00	42.00	39.41
Jun	27.21	62.00	54.00	47.74
Jul	35.26	73.00	63.00	57.09
Aug	38.17	76.00	67.00	60.39
Sep	38.62	70.00	61.00	56.54
Oct	36.93	59.00	54.00	49.98
Nov	40.5	63.00	59.00	54.17
Dec	46.53	61.00	58.00	55.18
Ann	37.47	62.50	56.5	52.16

V. CONCLUSIONS

In this study, Direct Solar Radiation, Direct Normal Irradiance, Diffuse Horizontal Irradiance and Global Horizontal Irradiance, Temperature and Humidity in Sohar-Oman has been measured and compared with NASA SSE Model and Department of Meteorology-Oman. This data is useful for solar technologies (i.e., photovoltaic, concentrated solar power, solar water heater,...etc). The hourly solar radiation data has been measured in Renewable Energy Lab-Sohar University. It is found that solar radiation is more than 600 W/m² throughout the year. Also, it is found that the maximum and minimum solar radiations are 6.84 and 4.10 kWh/m²/day. The clearness index is calculated to be 0.575. The highest and lowest average temperature found is 34.59 °C and 20.51 °C in June and January, respectively. Finally, the average highest and lowest humidity found is 60.39 and 39.41 in August and May, respectively.

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Dr Hussein has completed two research projects granted as Principle Investigator and Co-Investigator by The Research Council of Oman (TRC). Also, he has new TRC-ORG grant and TRC-FURAP projects. His current researches interests are in the area of Photovoltaic's, Renewable Energy, Power Electronics, Power Quality and Electrical Power System. Hussein is chairman of the Renewable Energy & Sustainable Technology Research Group in Oman. Hussein is the team leader of Generation & Storage taskforce in Oman Renewable Energy Strategic Program.